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C J Mitchell and A J Bloodworth

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British Geological Survey
Keyworth, Nottingham NG12 5GG, UK

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British Geological Survey

Mineralogy and Petrology Report WG/89/21R

EVALUATION OF PUMICE FROM COSTA RICA AS LIGHTWEIGHT AGGREGATE

C. J. MITCHELL AND A.J. BLOODWORTH

INTRODUCTION

This report describes the mineralogy, chemistry and physical properties of two pumice samples from Zarcero, Costa Rica, as a means of assesssing their suitability as lightweight aggregate. This work was carried out in support of Projecto Anglo-Costarrecense de Minerales Industrializables (PACOMI), a bilateral technical cooperation project between the British Geological Survey (on behalf of ODA) and the Direction de Geologia, Minas y Hidrocarbuos (DGMH), Costa Rica. It is intended that this report should provide sufficient information on laboratory procedures to enable PACOMI to devise a testing scheme to screen large numbers of potential lightweight aggregate samples using the relatively simple equipment available in Costa Rica. Accordingly, a number of relevant test procedures are described in detail in Appendices 1-5.

Definition of pumice

Pumice is a pale coloured, highly vesicular volcanic glass, usually occurring as massive blocks or unconsolidated, fragmented material. It is formed from silicic lava rich in dissolved volatiles particularly water vapour, which on eruption generates a frothy mass. This mass may solidify on contact with the atmosphere as a vent filling or flow, or may be shattered by a violent eruption (Robbins, 1984). Fragmented pumice with shards under 2 mm in diameter is generally defined as pumicite (Peterson & Mason, 1983).

Industrial applications of pumice

Pumice is valued for properties such as low bulk density, good thermal and sound insulation, and abrasiveness. The largest consumer of pumice is the construction industry. The use of pumice as lightweight aggregate in concrete results in a 25 percent weight reduction over normal aggregate, with negligible loss of compressive strength. This enables easier handling of concrete blocks and a reduction in reinforcement and foundation requirements. Other industrial applications of pumice are as a carrier for pesticide, as a soil additive for moisture retention, in drainage and sewage filtration, in insulation, as an abrasive, as a pozzolanic additive to concrete and for 'stone washing' jeans (Robbins,1984).

SAMPLES

Two samples of pumice were collected bv one of the authors in March 1989 from the Zarcero area, North West of San Jose, Costa Rica. The pumice deposits in this region are relatively thick and are associated with Quaternary volcanic activity (Bloodworth, 1989). Approximately 12 kg of unconsolidated material were obtained from each of two quarries to the North West and South of Zarcero; these were labelled JB 77 and 78 respectively.

Both samples are light grey in colour, with JB 77 having a slightly pale greenish grey coating over most lumps. The fresh pumice surfaces are white in both samples. Dark brown friable rock fragments occur in both, especially in the coarser part of JB 78. Both samples, as dug, had a slightly damp appearance, which suppressed the considerable fines content, and on drying the pumice is very dusty.

MINERALOGICAL AND CHEMICAL EXAMINATION

Thin section microscopy

Seven resin impregnated polished thin sections were made, four of JB 77 (two of pumice and two of rock fragments) and three of JB 78 (one of pumice and two of rock fragments). All the thin sections were studied under transmitted light. The rock fragments are andesitic, with large augite phenocrysts and complex twinned plagioclase feldspars. The pumice thin sections did not reveal very much information as the pumice glass and resin-filled bubble cavities were virtually indistinguishable. Flow textures of elongated bubbles could be made out, as well as the occasional phenocryst of plagioclase feldspar or biotite mica.

Back-scattered electron images of the pumice thin sections contrast the bubble cavities as black and the glass as white due to the difference in electron density. Figure 1 shows a representative section of JB 77 with rounded bubble casts and the skeletal framework of glass. The bubble casts range in size from a few microns up to 100 µm in diameter, with the average bubble size around 20 µm in diameter. Larger areas of porosity exist which possibly represent accumulations of several bubble casts. Figure 2 shows flow structures within JB 77 where the bubbles are stretched out into thin lamellae, the glass appearing to 'wrap' itself around the bubble casts. The presence of flow structures in pumice indicates a very slow viscous 'creep' which deforms the bubbles present in the virtually solidified mass. Figure 3 shows a representative section of JB 78 similar to Figure 1 but with larger areas of interconnected bubble casts, and more bubble casts containing broken fragments of glass (probably created during the thin sectioning of the pumice). Figure 4 shows an area of very high porosity; this photomicrograph is on the same scale as Figure 3, with the glass only present as slivers and shards. Flow structures do occur in JB 78 although these are not as well developed as in Figure 2. Phenocrysts occur in both samples, these including plagioclase feldspar, apatite, biotite mica, and hornblende. The higher porosity, and areas of broken glass

fragments within the bubble casts, indicate that JB 78 probably has lower compressive strength than JB 77. This observation ties in with the aggregate impact values, which show JB 77 to be almost twice as strong as JB 78 (see Table 5).

The same thin sections were also studied by electron microprobe; the glass forming the matrix of the pumice was analysed for major element composition (see Table 1 for the analysis of the glass of JB 77). The silica content ranged from 64.67 to 76.55%, with most analyses being between 70 and 74% (which is relatively high). Alkali, FeO and CaO contents all increased with a decrease in silica content. Na_2O ranged from 1.9 to 6.1%, K_2O from 2.73 to 4.35%, FeO from 1.22 to 2.06% and CaO from 1.25 to 5.35%. MnO, TiO2, Cr203 and MgO contents were all too low to be statistically reliable. These data were plotted on AFM [(Na_2O + K_2O) - FeO - MgO] triangular diagrams (see Figures 5 and 6), along with typical analyses for andesite and rhyolite. The pumice samples plot much nearer the alkali corner of the AFM triangle, and are slightly lower in FeO than rhyolite and much lower in FeO and MgO than andesite. The pumice samples plot at the rhyolitic end of the calc-alkaline volcanic trend,(Hatch, Wells and Wells, 1961), indicating that they are acid volcanic rocks. The area that they are derived from is characteristically a calc-alkaline volcanic terrain, as indicated by the lumps of andesite that occur in the bulk samples, and as the pumice are acid volcanics they probably represent the first stages of volcanic activity.

X-ray diffraction

X-ray diffraction was carried out on the <150 µm diameter pumice fraction produced by grading of the samples (in the 'as dug' state); minerals identified included albite and anorthite feldspars, biotite, augite and illite. The glass forming the bulk of the pumice is amorphous and gives no X-ray diffraction peaks. This indicates that the pumice may be prone to reaction with alkali from cement. The presence of illite, possibly formed by the devitrification of the glass matrix of the pumice, suggests that the pumice fines could not be used as a pozzolanic additive. The clay mineral alteration products probably make up a large proportion of the <150 µm fraction. As alteration products naturally form on the outside of particles they would interfere with, and weaken, cement bonds.

PHYSICAL PROPERTIES

Grading

The grading, or particle-size distribution, of an aggregate refers to the size range of the material produced by passing it through a series of sieves, in a regularly decreasing aperture size. The natural grading of the aggregate is crucial as it dictates the end-use of the material. The bulk density of lightweight aggregate is partly controlled by its particle-size distribution. A coarse aggregate with little or no fines will have a lower bulk density than an aggregate with a higher fines content. This is due to the fact that fine material has greater compaction than coarse material, and therefore a higher bulk density. Too much coarse or fine material will

inevitably require expensive crushing and/or screening to produce a material with a useful size range. Different specifications exist to control the size range of aggregates for different purposes. A particle diameter of 5 mm divides coarse from fine aggregate: typically, coarse aggregate contains a majority of particles over 5 mm and fine aggregate contains a majority of particles under 5 mm. Too much very fine material, i.e. material under 150 µm in diameter, will increase the cement consumption in concrete and also increase the bulk density, reducing those advantageous properties of lightweight aggregate. Controlling the size range of the aggregate is important, but maintaining a slightly bimodal distribution has the advantage of increasing the amount of compaction that can be achieved. Fine and coarse aggregate is deliberately mixed to produce suitable aggregates. Fines are useful in their own right, with sub millimetre material appropriately used as grinding and polishing abrasives, and as pozzolanic additives. Coarse aggregate is useful as filtration media, insulation, etc...

Approximately 1 kilogram of each pumice sample was sieved through the aggregate sieve series (see Appendix 1 for the method) and the results are given in Table 3 as percentage finer than the sieve size. Also, the data are plotted on a semi-logarithmic graph to produce grain-size distribution curves in Figure 7. As can be seen, most of the particles in both samples are under 150 µm in diameter (30 % of JB 77 and 25 % of JB 78). The samples can thus be designated 'fine' aggregates as approximately 80 % of both are less than 5 mm in diameter (5 mm is the divide between fine and coarse aggregate, BS 882:1983). Both particle-size distributions are roughly the same, with JB 77 being slightly finer; this is confirmed by the medium size (diameter at 50 % cumulative percentage on the grain size distribution curves) of JB 77 which is 1.2 mm and that of JB 78 2.3 mm.

Bulk density

The bulk density represents the density of the material as a whole, including the porosity and interparticle space. It is strongly influenced by specific gravity, particle shape and particle-size range. Bulk density measurement involves determining the volume that a specific weight of aggregate occupies. These measurements should be carried out on the ungraded and graded aggregate, to enable comparison with commercial grades, as different suppliers express bulk density in either of these ways. Bulk density strongly influences the weight of construction material; thus using lightweight aggregate reduces the need for excessive strengthening of buildings. The preference for lightweight aggregate is that it should have the lowest bulk density possible but that this falls within the range 500 - 1000 kg/m^3.

Bulk density was measured in the 'as dug' and graded states (see Appendix 2 for the method). The results in Table 4 show how the bulk density increases with decreasing particle size, from 450 kg/m^3 (for the +10 mm fraction) to 820 kg/m^3 (for the -300 µm fraction) for JB 77 and from 570 kg/m^3 (for the -10+5 mm fraction) to 1020 kg/m^3 (for the -300 µm fraction) for JB 78. The +10 mm fraction of JB 78 does not follow the trend, the bulk density being 708 kg/m^3 (over 100 kg/m^3 higher than the next size range down), probably

resulting from the large proportion of andesite fragments present in this fraction. The 'as dug' bulk densities of JB 78 (976 kg/m^3) are higher than those of JB 77 (552 kg/m^3), probably due to a larger proportion of andesite, higher specific gravity of the glass itself and a lower porosity.

Aggregate impact value (AIV)

The aggregate impact test does not measure compressive strength but the resistance to pulverisation by a fixed amount of impaction. This resistance will depend on such factors as the particle shape, composition, degree of weathering and/or alteration, and porosity. It will give a good indication, along with other properties, of the toughness of the aggregate. The AIV is more directly relevant to assessing aggregate for use in roads, but gives a general indication of its suitability for construction.

Three samples of pumice, in the size range -14 +10 mm, from both JB 77 and JB 78 were tested (see Appendix 3 for the method used) and an average of each set of three figures was taken to be the AIV of each sample. Values of 66 were obtained for JB 77 and 34.8 for JB 78. The lower value for JB 78 is probably due to the higher proportion of andesite lumps, with the majority of the plus 2.36 mm material being andesite, with the pumice preferentially crushed. The higher specific gravity of JB 78 indicates a lower silica content which would lower the hardness and hence the aggregate impact value. Where high AIVs occur, i.e. over 26, the fines act as a buffer to the impact stress by infilling interparticle gaps, and only aggregate with AIV values less than 26 would be considered strong enough for use in roads in the UK, (Geological Society, 1985).

Apparent specific gravity and water absorption

The specific gravity of an aggregate is a combination of the specific gravities of the component minerals and/or materials. It is useful in confirming the bulk density values, but is secondary to determination of the water absorption. Water absorption is an indication of the amount of water an aggregate can contain before it is saturated; a value for the porosity can also be obtained, but both are dependent on the total saturation of the aggregate, which may not be achieved if the aggregate is not very permeable. Water absorption gives an indication of the suitability of the aggregate for such uses as insulation, filtration and as a pesticide carrier.

Specific gravities (see Appendix 4 for the method used) of JB 77 is 1.85 g/cm^3 and JB 78 is 2.23 g/cm^3. This difference between the samples partly depends on the difference in bulk density values. The percentage voids, 38 % for JB 77 and 23 % for JB 78, also agrees with the difference in bulk density, as it indicates that JB 77 has a higher porosity than JB 78. The water absorption is 58.9 % for JB 77 and only 35 % for JB 78. The higher percentage voids and water absorption figures for JB 77 seem to indicate that it has a higher porosity, whereas the photomicrographs of the two samples suggest the opposite. It is possible that JB 77 has a

higher permeability than JB 78, which would account for the apparently contradictary difference between void percentage and water absorption figures, and the porosity suggested by the photomicrographs. Unfortunately the photomicrographs do not suggest a difference in permeability between samples.

Loss-on-ignition (LOI)

Loss-on-ignition is defined as the percentage weight loss of aggregate subjected to a temperature of 800 ^{o}C. for two hours (BS 3681:1963). LOI gives a good indication of the presence of deleterious substances, such as carbon (plant matter, coal, etc..), clay minerals (especially smectites), carbonates and sulphates (especially gypsum). A high LOI would prompt more detailed examination (for instance, complete major element analysis) if the aggregate was being considered as a pozzolanic additive or to gauge its reactivity with cement when used in lightweight concrete.

Loss-on-ignition was carried out on each sample (see Appendix 5 for the method used), the results are given in Table 5, and are high in comparison with those of commercially available pumice. This is possibly due to the presence of alteration products such as illite, which will dehydroxylate at the loss-on-ignition temperature of 800 ^{o}C. High LOI will therefore indicate potential problems if the aggregate is considered for use as lightweight aggregate in concrete or as a pozzolanic additive.

Comparison with commercial grades

The Costa Rican pumice compares favourably with commercially available pumice, as can be seen in Tables 1-5, although data available on commercial grades are not comprehensive enough to enable thorough comparison. Comparison is often problematic as the data often refer to graded products and not the material as it is extracted from the ground.

The chemical analyses available for commercial pumice (as shown in Table 2) show that the Costa Rican pumice is of similar composition. SiO_2 contents are from 60-74 %, most being in the range 70-74 %. Alkalis, CaO and FeO all fall within the same ranges, and have the same inverse relationship with silica. This indicates that the Costa Rican pumice samples do not suffer from a contamination problem, i.e. a high FeO/Fe_2O_3 content might colour the pumice brown and prejudice its potential use. Such contamination could be due to weathering or groundwater percolation through the material. The AFM plot in Figure 6 shows commercial pumice plotted along with the Costa Rican pumice, and plot close together.

Table 3 compares the grading of the Costa Rican pumice against two commercially available samples, Italpomice and Pumex. The former has a very similar grading whereas the latter is coarser (with little material below 2 mm in diameter), but as these are commercial grades they have artificially produced particle-size distributions. Screening of the Costa Rican

pumice would produce a pumice with a commercially acceptable particle-size distribution.

The bulk density of the Costa Rican pumice has the same range of values as commercial grades which are generally between 400-1000 kg/m^3 and they also increase with a decrease in particle size, as shown in Table 4. Table 5 highlights the paucity of information available on certain miscellaneous properties, indicating the significance some suppliers attach to them, but this also could be a reflection of the fact that pumice is dominantly used as a lightweight aggregate for concrete. Only JB 78 has comparable specific gravity to commercial grades, although that of JB 77 is not that far removed. The only available aggregate impact value is that of Italpomice pumice which is midway between the Costa Rican samples. The loss-on-ignition figures of the Costa Rican pumice samples are higher than commercial grades by about 1-2 %, which could be problematic if this represents minerals deleterious to concrete.

DISCUSSION

The evaluation of pumice as a lightweight aggregate should include, at the very least, determination of grading, bulk density and aggregate impact value. Grading is important as the proportion of fine and coarse material predicts the end use, and the production of a particle-size distribution enables a direct comparison with commercial grades as many producers do little other than screen their pumice. However, the sieving action itself helps break down the brittle pumice producing a slightly artificial particle-size distribution. Bulk density determinations indicate whether the material is light enough to be considered a 'lightweight' aggregate, and usually the lighter the better as this reduces the cost of construction when used in lightweight concrete. Aggregate impact testing gives an indication of the strength, which is important as the major use is for lightweight structural concrete. During testing the aggregate often becomes compressed such that it is difficult to remove from the test container and pieces may break down on removal, which produces a result indicating the pumice to be slightly weaker than it actually is. All three tests are simple and quick, producing enough information on their own to assess the usefulness of a pumice, especially for use as a light weight aggregate for concrete.

Although mineralogical and chemical properties do not feature strongly - if at all - in commercial specifications for lightweight aggregate, these are useful for providing background information on the material and possibly highlighting problems in use, such as alkali-aggregate reaction. Soft inclusions (such as clay lumps and organic material) will easily disintegrate, may interfere with the chemical reactions of cement hydration and should be limited to less than 2-5 %. Other 'unsound' particles such as mica, gypsum (and other sulphates), iron pyrites and marcasite will react with chemical agents produced during cement hydration, with the latter two being the most common expansive inclusions found in aggregate. Clay and other fine material will either form coatings around the aggregate particles, or occupy the interstices, and generally increase the amount of water required for sufficient hydration of the cement; BS 882:1973 limits fine material to 1% in coarse

aggregate (Neville, 1981).

Fine-grained forms of silica (such as opal, chalcedony and tridymite) are found in rhyolitic to andesitic tuffs (as well as other rock types), which are closely related to pumice. These forms of silica will react with hydroxides produced from alkalis present in cement to form an alkali-silicate gel. This gel will absorb an almost unlimited amount of water and swells accordingly. This expansion leads to a build up of pressure on the surrounding cement, which eventually cracks forming 'pop-outs'. The reactivity of the silica is controlled by the particle size (20-30 μm in diameter will lead to expansion within about a month or two) and porosity. As little as 0.5 % of the aggregate taking place in the reaction can cause damage to the concrete.

The degree of porosity can be gauged from a thin section; this has a direct bearing on insulation and absorption, and also indirectly on strength and durability. The degree of interconnection of pores, and the presence of cracks, will indicate the likely permeability. Also highly porous material is prone to frost damage, with the critical factor being the proportion of pores under about 4-5 μm in daimeter. These pores let water enter, but do not readily allow it to drain away, such that it causes particle splitting and disruption of the cement when the pore water expands on freezing.

Further evaluation can be carried out using a scanning electron microscope and an electron microprobe. The former will enable a closer inspection of the surface textures of the aggregate, and the porosity. The latter enables the chemistry of the aggregate to be determined, which will help identify the rock type and also indicate the presence of deleterious elements.

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C. J. Mitchell
A. J. Bloodworth

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APPENDIX ONE : GRADING

1:1 Apparatus

1:1:1 Sieves

Sieves made to BS 410 (specification for test sieves) are recommended; they are essentially 20 cm diameter frame brass sieves with steel mesh, or perforated steel plate for the larger aperture sieves. The following sieve series should be used :

14 mm, 10 mm, 5 mm, 2.36 mm, 1.18 mm, 600 microns, 300 microns and 150 microns.

Sieves with a larger frame diameter should be used for large sample weights, i.e. over that recommended below. The sieves should be stackable from the coarsest at the top progressively decreasing in mesh aperture diameter down to the finest at the bottom. A lid and pan are required to prevent loss of material.

1:1:2 Balance

A balance sensitive, and accurate to 0.1 percent of the test load, i.e. one gram in one kilogram, should be used.

1:1:3 Drying oven

An oven of appropriate size, and capable of maintaining a uniform temperature of 110^{0}C.

1:2 Sample

The amount of sample used to determine the grading, or grain-size distribution, depends upon the nominal maximum particle size of the pumice, which is determined by the diameter at which 95 % of the pumice would pass through. For both pumice samples JB 77 and JB 78 this nominal maximum size is 10.3 mm; the recommended sample weight is 1 kg for 9.5 mm and 2 kg for 12.5 mm (ASTM C136), and 0.25 and 0.5 kg respectively (BS 3681). The recommended sample weight is one kilogram.

The sample should be dried at 110 ^{0}C for 24 hours, and allowed to cool prior to sieving. A damp sample will stick to the sieves, fines will cling to larger lumps and clog the sieve apertures. The weight of sample should be recorded accurately, as comparison with the final combined weight of sieve fractions is required.

1:3 Procedure

When sieving one kilogram of pumice, split the sample into five 200 g portions, i.e. sieve no more than 200 g at a time to allow all the particles to reach the sieve openings several times during sieving. (The recommendation of a maximum of 6 kg/M^3 equates to 194 g for a sieve with a 20 cm diameter frame (ASTM C136).). Sieve the pumice through the coarsest to the finest sieves. It is recommended not to use a mechanical sieve shaker, but to hand sieve, i.e. pass the material through one sieve at a time, with pan and lid in place. Shake the sieve carefully to and fro, side to side, in anticlockwise and clockwise circular motions, and occasionally shake the sieve up and down. Do not shake too vigorously, carry out each action ten times and remove pan. Shake the sieve over a tray and only continue sieving if an appreciable amount of pumice passes through. Sieving will take longer using the finer aperture sieves. It is acceptable to place coarse pumice particles, i.e. those over 10 mm in diameter, through sieve holes, but do not force the pumice through.

When no more material will pass through, carefully brush off the pumice retained on the sieves and record the weight. The total weight of all the sieve fractions combined should not deviate from the starting weight by more than 1 percent, i.e. ten grams for one kilogram.

1:4 Calculation

Calculate the percentage of material falling into each size range by dividing the weight retained on each sieve by the total weight of all the sieve fraction weights combined, e.g. in the -5 mm +2.36 mm size range. Then calculate the 'cumulative less than' percentages, i.e. the percentages of material less than a certain size, for each of the sieve sizes, by combining the size range percentages for material finer than each size, i.e. for the percentage less than 5 mm add up the percentages of the -5 mm +2.36 mm down to the -150 micron sieve fractions. Then plot the 'cumulative less than' percentages against their respective sieve sizes on semi-logarithmic chart paper to provide cumulative grain-size distribution curves. Alternatively, plot the sieve fraction percentages against their size ranges to produce 'gaussian' type particle-size distribition curves.

1:5 Comments

Dry sieving of the pumice usually results in material breaking down, which is unavoidable due to its brittle nature. Wet sieving would produce a more accurate size distribution, but due to particle porosity the fractions would have to be thoroughly dried before weighing and this would make size analysis much more time consuming. Dry sieving is considered preferable, as long as care is taken not to break down the pumice excessively.

APPENDIX TWO : BULK DENSITY

2:1 Apparatus

2:1:1 Balance

Balance as in section 1:1:2.

2:1:2 Bulk density container

A water tight cylindrical metal container, preferably fitted with handles, with the following dimensions :

Three litre capacity; inside diameter 15.5 cm; inside height 16 cm; thickness of the bottom 5 cm, and of the walls 2.5 cm. Top of the container must be level (BS 812 : 1975.)

The dimensions of this container are for aggregate with a nominal maximum size of 12.5 mm.

2.2 Sample

The sample is used graded or ungraded, as long as the state of grading is recorded along with its corresponding bulk density value. The sample is oven dried at 110 ^{0}C for 24 hours and cooled. Enough sample must be dried so as to enable the test to be carried out at least twice, although repeat determination on the same sample is permissible, but with a tighter agreement required on the values produced.

2:3 Procedure

The container is filled to overflowing with pumice using a scoop, taking care not to segregate the pumice, and discharging it from a height not exceeding 5 cm over the top of the container (known as the shoveling procedure). Level the surface of the aggregate such that no pumice projects above the top level of the container, and there are no major depressions. Lightweight aggregate is not tamped down or the container tapped; tamping would break down the pumice and the following decrease in particle size would result in an increase in the bulk density. The weight of the aggregate is determined, and the procedure is repeated. (BS 812 : 1975, ASTM C29.)

The volume of the container is determined by filling it with water such that no meniscus is present above the rim and determining the weight of the water. The temperature of the water is also measured.

2:4 Calculations

First the unit weight of the water is determined from the table below

TABLE 5 : Unit weight of water

Temperature		
^{o}F	^{o}C	kg/m^3
60.0	15.6	999.01
65.0	18.3	998.54
70.0	21.1	997.97
73.4	23.0	997.54
75.0	23.9	997.32
80.0	26.7	996.59
85.0	29.4	995.83

(ASTM C29)

and the unit weight is divided by the weight of water required to fill the container to produce a factor. The weight of the aggregate is multiplied by this factor to produce the uncompacted bulk density in kg/m^3. The results of two separate determinations should agree by 32 kg/m^3 (ASTM C29), if not then the bulk density determinations should be repeated. If they do agree the bulk density value is taken as the average of two results.

APPENDIX THREE : AGGREGATE IMPACT VALUE (AIV) (BS 812 : Part 3 : 1975)

3:1 Apparatus

3:1:1 Balance

A balance of at least 500 g capacity and accurate to 0.1 g is required.

3:1:2 Impact testing machine

The impact testing machine consists of a frame with a free sliding weight attached to it, and a cylindrical steel container for the aggregate. The dimensions of the machine, and cylindrical steel cup, are given in Diagram 1. During operation the machine is firmly fixed on a concrete or stone block or floor, at least 45 cm thick.

3:1:3 BS test sieves

Sieves of apertures 14 mm, 10 mm and 2.36 mm are required for the standard test; the

sieves for non-standard testing are given below:

TABLE 6 : Non-standard sieve sizes

For sample preparation		For separating Fines	
Passing	Retained		
mm	mm	mm	microns
10.00	6.30	1.70	-
6.30	5.00	1.18	-
5.00	3.35	-	850
3.35	2.36	-	600

3:1:4 Metal tamping rod

A metal tamping rod of 1 cm diameter circular cross section, 23 cm long and rounded at one end.

3:2 Sample

The sample is graded -14mm +10mm, with enough sample for at least two tests being available. The sample is tested surface dry, and if dried, this must not be for more than 4 hours at 110^{0}C. The sample is allowed to cool to room temperature before testing.

3:3 Procedure

The cylindrical steel container is filled one third at a time, tamping down 25 times with the rod in between filling; once full the aggregate is levelled off such that none projects over the top of the container. Any aggregate projecting is removed and any obvious depressions are filled.

The height of the impact weight over the cylindrical cup before testing must be 38 +/- 5 cm and the weight must fall freely. The filled container is placed below the weight in the impact testing machine and is subject to 15 blows, with not less than one second interval in between blows. The aggregate is removed by tapping the underside of the upturned container with a rubber mallet (the shocks produced by a metal hammer might break down the pumice further). If the crushed aggregate is packed in so tight that it refuses to dislodge then pieces must be worked free carefully until all is removed. Use a sieve brush to clear any fines sticking to the base. Take care not to lose any pumice at this stage. Pass the crushed pumice through a 2.36 mm sieve; any compressed fines of pumice must be carefully rubbed to disaggregate them to their actual particle size. Weigh that amount passing and that retained; if the two weights combined are less than the starting weight by more than one gram repeat the test.

3:4 Calculations

The following equation gives the percentage fines;

$$\text{Percentage fines} = \frac{B}{A} \times 100$$

A = Initial weight of sample
B = Weight of material finer than 2.36 mm.

and the average of two results, to the nearest whole number, is the aggregate impact value (AIV).

3:5 Non-standard test

Testing using other than the standard sizes can be performed by referring to section 3:1:2; aggregate over 14 mm can not be tested for aggregate impact value. Results from testing of smaller sized aggregate will not produce results which are comparable with those on the standard size range and will generally give a lower impact value. This is due to the increase in compaction and bulk density of finer aggregate. The reporting of aggregate impact values using non-standard aggregate must indicate the size range used so as not to confuse them with values obtained from standard aggregate.

3:6 Comments

The nature of the pumice produces a cake of compressed fines and lumps forming in the metal container, and care has to be exercised so as not to break down the pumice further. Lumps of compressed fines are rubbed carefully through the 2.36 mm sieve to reduce them to their actual particle size. The 'caking' effect of pumice after aggregate impact testing requires further investigation to assess its suitability for use as road stone.

APPENDIX FOUR : APPARENT SPECIFIC GRAVITY AND WATER ABSORPTION

4:1 Apparatus

4:1:1 Glass cylinders

Two tall glass cylinders of approximately 1 1/2 litres capacity each, with flat rims such that a flat circular glass disc can be slipped over the top to create an air tight seal (some grease will help provide an effective seal).

4:1:2 Balance

As in section 1:1:2.

4:1:3 Drying oven

As in section 1:1:3.

4:1:4 Deep metal tray

A metal tray large enough to contain at least three litres of water.

4:2 Sample

The sample required is twice the amount that will fill one of the glass cylinders to approximately three quarters full, so as to enable a repeat determination. The sample must be dried at 110°C for 24 hours and allowed to cool prior to the testing, and weighed.

4:3 Procedure

The sample is soaked in the metal tray, preferably using distilled water, for 24 hours to totally saturate it. The samples are dried until 'surface dry' but still saturated, and weighed. The best means of accomplishing this is to dry the saturated sample in the metal tray and check every ten minutes. The 'surface dry' but still saturated state is reached when the sample first becomes free flowing (this indicates that the sample is surface dry as the effects of surface tension have disappeared, i.e. the sticking together of wet particles is due to the surface tension of the water on the surface of the particles). Problems may arise due to the formation of a cake of fine pumice on the bottom of the metal tray. Deciding when the pumice sample is 'surface dry' but still saturated is very subjective.

The 'surface dry' but still saturated pumice is poured into the glass cylinder and the container is then filled to the brim with water. The water is allowed to soak into the pumice and water is added until no more is required to keep the container full. A period of 24 hours should be sufficient to produce a pumice that will be as saturated as possible. The glass disc is placed on top of the container, sealing it such that there are no air bubbles trapped in the container. The container with pumice and water is weighed. The container is emptied and then reweighed containing just water (and the glass disc in place). The saturated pumice is dried at 110 °C for 24 hours and reweighed.

4:4 Calculation

Apparent specific gravity, water absorption and void percentage are calculated using the following equations :

$$\text{Specific gravity on oven dried basis} = \frac{D}{A - (B - C)}$$

$$\text{Apparent specific gravity} = \frac{D}{D - (B - C)}$$

$$\text{Water absorption} = \frac{100\,(A - D)}{D}$$

$$\text{Percentage voids} = 100 \times \left(\frac{\left(\frac{b}{a} - 1000 \right)}{a} \right)$$

A = Surface dry, but saturated, aggregate weight
B = Weight of container, aggregate and water.
C = Weight of container and water.
D = Dried aggregate weight.
a = Apparent specific gravity on oven dried basis
b = Bulk density, kg/m^3

(BS 812, ASTM C136)

Essentially, this technique determines the volume of aggregate by the amount of water it indirectly displaces, assuming the specific gravity of water to be 1 g/cm^3. With the aggregate weight known, the specific gravity can be calculated. Water absorption is an indication of the amount of water an aggregate can contain before it is oversaturated. Percentage voids calculates the porosity and interparticle space of the pumice.

4:5 Comments

The attainment of a 'surface dry, but saturated' pumice is considered to be a somewhat subjective part of the water absorption test, relying on judgement rather than a fixed point. Also saturating pumice with water is not possible because the fact that many bubble cavities are not interconnected makes pumice partially impermeable, although highly porous. Resultant undersaturation of pumice during the test leads to lower values for both apparent specific gravity, water absorption and void content.

APPENDIX FIVE : LOSS-ON-IGNITION (LOI)

5:1 Apparatus

5:1:1 Ceramic crucibles

Two small ceramic crucibles of at least a one gram capacity each and able to withstand a temperature of at least 800 ^{0}C.

5:1:2 Balance

As in section 1:1:1.

5:1:3 Furnace

A small muffle furnace able to contain at least two small crucibles and capable of sustaining, and holding a temperature of 800 ^{0}C for at least two hours.

5:2 Sample

A sub-sample of aggregate is ground to pass 210 µm, and two one-gram samples are split off from this.

5:3 Procedure

Weigh the crucible accurately to three decimal places, add the sample and then reweigh. Place the sample and crucible in the furnace, at 800 ^{0}C, leave for 2 hours, then remove and allow to cool. Reweigh the sample and crucible. The procedure is repeated on a second sample.

5:4 Calculation

The loss-on-ignition value is derived as follows :

$$\text{Percentage weight loss} = \frac{(A-B)}{A-C} \times 100$$

A = Weight of crucible and sample
B = Weight of crucible and sample sfter heating
C = Weight of crucible

If the two results agree to within 1 % they are averaged, and the average percentage weight loss is given as the loss-on-ignition value (BS 3681 : 1963).

TABLE 1 : Chemical analyses (wt %) of Costa Rican pumice (JB 77) by Electron Microprobe

Oxides	1	2	3	4	5	6	7	8	9	10
Na_2O	1.90	2.55	3.40	2.91	4.70	4.58	6.10	3.39	3.97	3.30
K_2O	3.25	3.18	3.85	3.82	4.35	4.13	2.73	3.85	3.73	3.99
FeO	1.52	1.52	1.53	1.61	2.06	2.01	1.22	1.39	1.53	1.49
SiO_2	75.18	76.55	73.77	74.40	71.05	70.43	64.67	74.18	73.76	74.10
CaO	1.25	1.43	1.69	1.64	1.94	2.39	5.35	1.67	1.65	1.51
MnO	0.13	0.14	0.18	0.11	0.14	0.12	0.12	0.08	0.15	0.05
Al_2O_3	16.02	13.92	14.86	14.80	14.76	15.44	19.27	14.74	14.53	14.84
TiO_2	0.24	0.28	0.25	0.32	0.45	0.34	0.26	0.32	0.33	0.33
Cr_2O_3	0.14	0.03	0.00	0.02	0.00	0.05	0.00	0.00	0.00	0.01
MgO	0.38	0.42	0.45	0.38	0.56	0.52	0.28	0.38	0.36	0.40
Total	100.01	100.02	99.98	100.01	100.01	100.01	100.00	100.00	100.01	100.02

TABLE 2 : Chemical analyses (wt %) of commercial pumice

OXIDES	Lipari, Italy White	Lipari, Italy Black	Yali, Greece	Hekla, Iceland	S. Kyushu Japan	Armenia USSR
Na_2O	3.59	3.23	3.49	3.25	2.76	-
K_2O	4.47	3.83	4.21	2.27	2.61	-
Fe_2O_3	1.98	1.75	0.89	1.85	1.16	)
FeO	0.02	0.64	-	3.26	-	) 13 -) 24
TiO_2	0.11	0.14	-	0.58	-	)
SiO_2	71.75	70.90	70.55	66.29	73.08	60 - 74
CaO	0.7	1.36	2.36	2.7	1.34	1 - 4
MnO	0.07	0.09	-	0.13	-	-
Al_2O_3	12.33	12.76	12.24	15.9	13.84	-
MgO	0.12	0.06	0.10	0.62	0.28	3

(After Anon, 1970; Anon, 1977; O'Driscoll, 1989 and Robbins, 1984).

TABLE 3 : Grading of Costa Rican and commercial pumice

Diameter	Costa Rican Pumice		Italpomice, Lipari		Pumex, SpA	
	JB 77	JB 78	size		size	
	%	%	mm	%	mm	%
14 mm	96.4	96.8	12.5	100	20	100
10 mm	88.8	91.5	9	95	12	65
5 mm	78.1	80.3	6	67	8	50
2.36 mm	55.4	65.0		51	5	40
1.18 mm	44.1	53.9		40	2.5	9
600 µm	37.7	42.5		35		
300 µm	34.2	32.8		33		
150 µm	30.0	25.3		29		

(Commercial data after Anon, 1970, and Robbins, 1984).

TABLE 4 : Bulk densities of Costa Rican and commercial pumice

Size range tested	Costa Rican Pumice JB 77 kg/m^3	JB 78 kg/m^3	Italpomice, Lipari
			Bulk density range 400 - 900 kg/m^3
As dug	552	976	**Pumex, SpA**
			Bulk density range
+ 10 mm	443	708	600 - 900 kg/m^3
- 10 + 5 mm	468	574	**Hekla, Iceland**
			Ungraded 380 kg/m^3
- 5 + 1.18 mm	512	690	
			Yali, Greece
- 1.18 mm			0 - 15 mm 550 kg/m^3
+ 300 µm	522	959	0 - 8 mm 700 kg/m^3
			0 -6.5 mm 750 kg/m^3
- 300 µm	821	1016.3	5 - 8 mm 600 kg/m^3

(Commercial data after Anon, 1970; Anon, 1977, and Robbins, 1984)

TABLE 5 : Apparent specific gravity, water absorption, aggregate impact value, loss-on-ignition, and void percentage of Costa Rican and commercial pumice

Physical property	Apparent specific gravity (g/cm^3)	Water absorption (%)	Aggregate impact value (%)	Loss on ignition (%)	void percentage (%)
Costa Rican					
JB 77	1.85	58.9	66	8	38
JB 78	2.23	35	34.8	6	23
Italpomice, Italy					
White	2.3	-	56	3.99	-
Black	2.4	-	-	-	-
Hekla, Iceland	2.56	-	-	1.4	-
Armenia, USSR	2.2 - 2.5	-	-	-	-
Yali, Greece	-	-	-	5.51	-
U.S. Pumice Company	-	-	-	0.7	-
S. Kyushu, Japan	-	-	-	4.77	-

(Commercial data after Anon, 1970; Anon 1977; O'Driscoll, 1989 and Robbins, 1984)

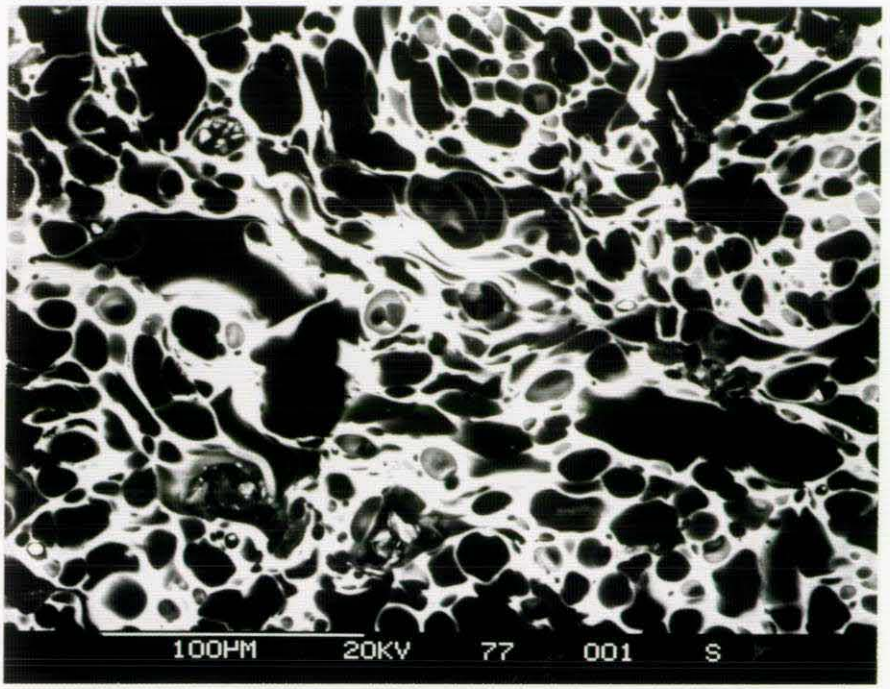


FIGURE 1: Pumice sample JB 77, SEM photomicrograph taken under back scatter conditions. The black areas are the bubble cavities and the white areas are the pumice glass.

FIGURE 2: Pumice sample JB 77, with laminar stretched bubble cavities due to flow of the pumice before final solidification.

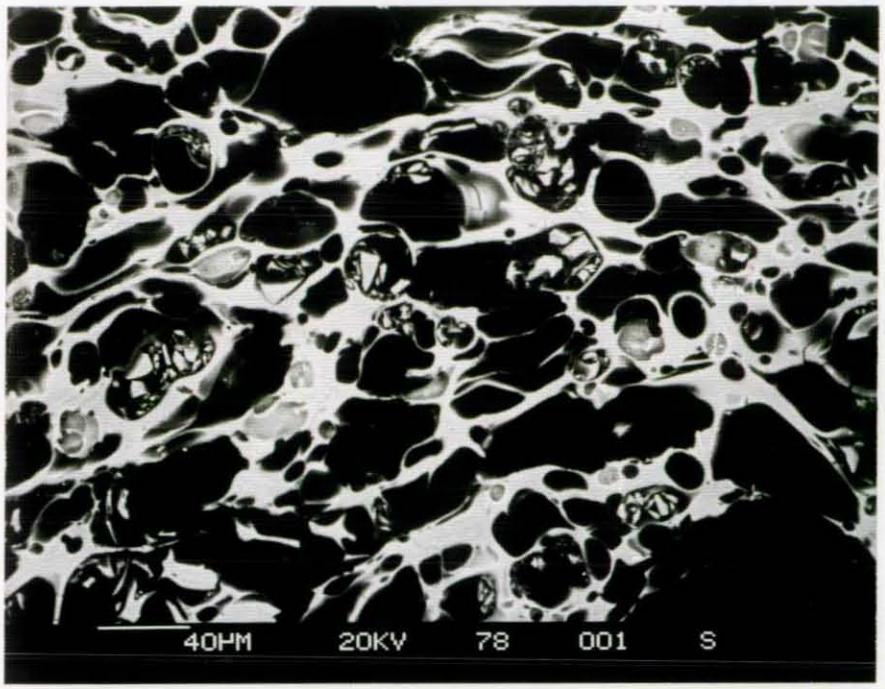


FIGURE 3: Pumice sample JB 78, SEM photomicrograph taken under backscatter conditions. The black areas are the bubble cavities and the white areas are the pumice glass.

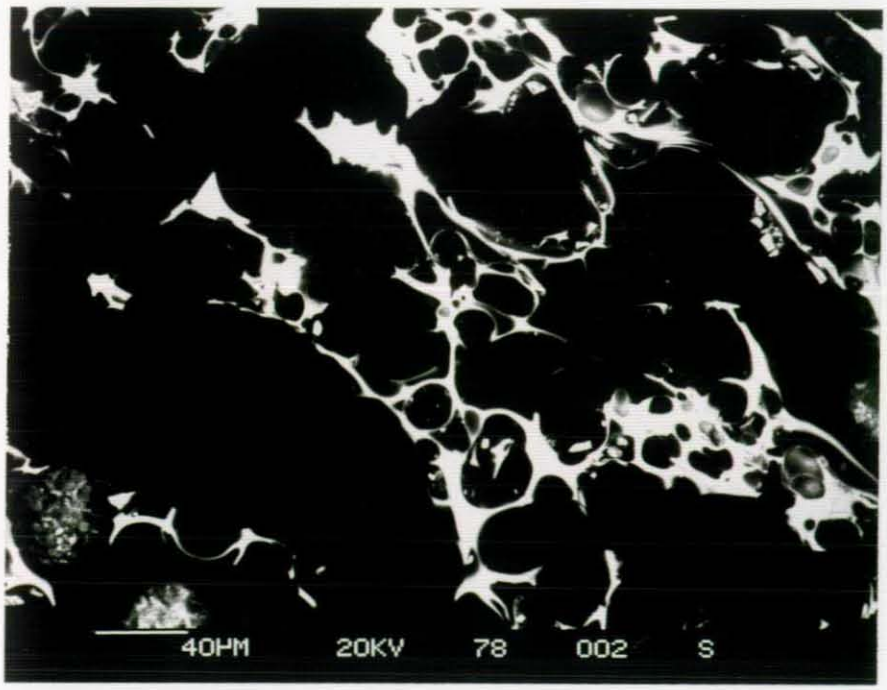
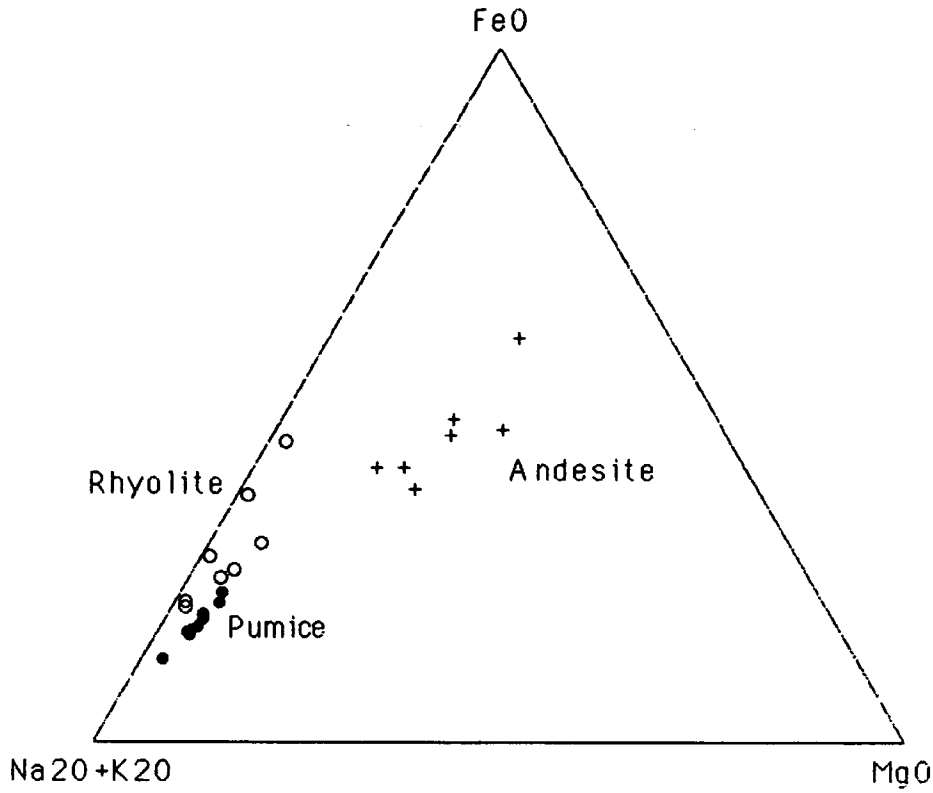


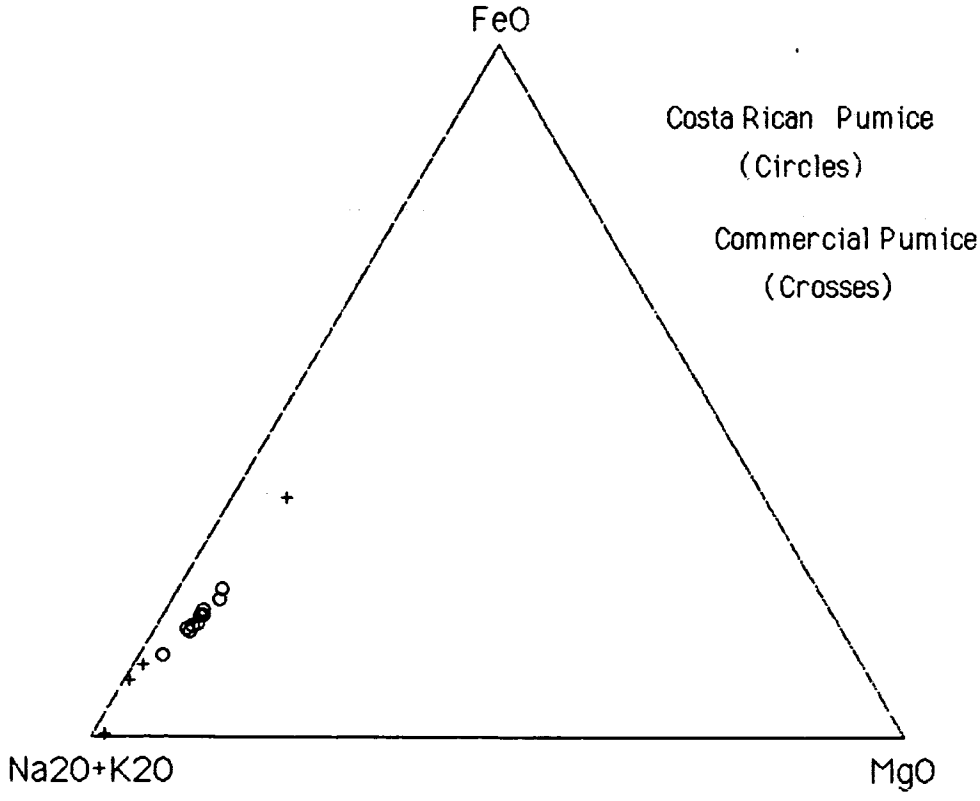
FIGURE 4: Pumice sample JB 77, with large areas of bubble cavities and little pumice glass.

Figure 5 : AFM plot of pumice glass with rhyolite and andesite



(Andesite and rhyolite data from Best, 1982; Hatch, Wells and Wells, 1961 and Hyndman, 1985)

Figure 6 : AFM plot of Costa Rican and commercial pumice



(Commercial data after Anon, 1970; Anon, 1977, and Robbins, 1984)

Figure 7 : Grain size distribution of Costa Rican pumice samples JB 77 and JB 78.

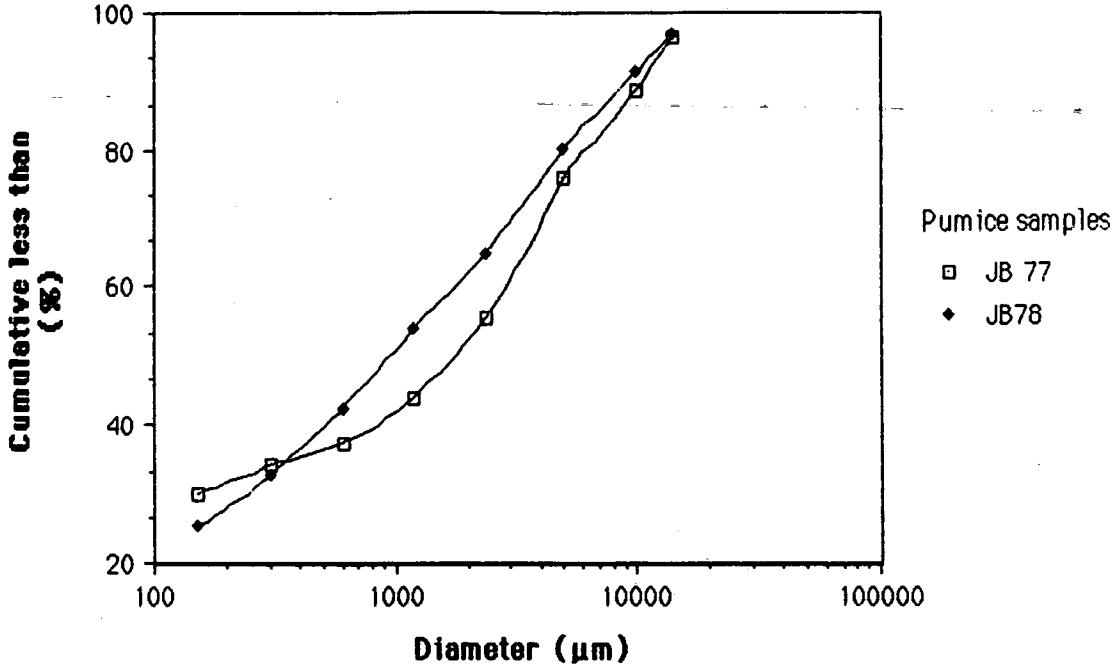
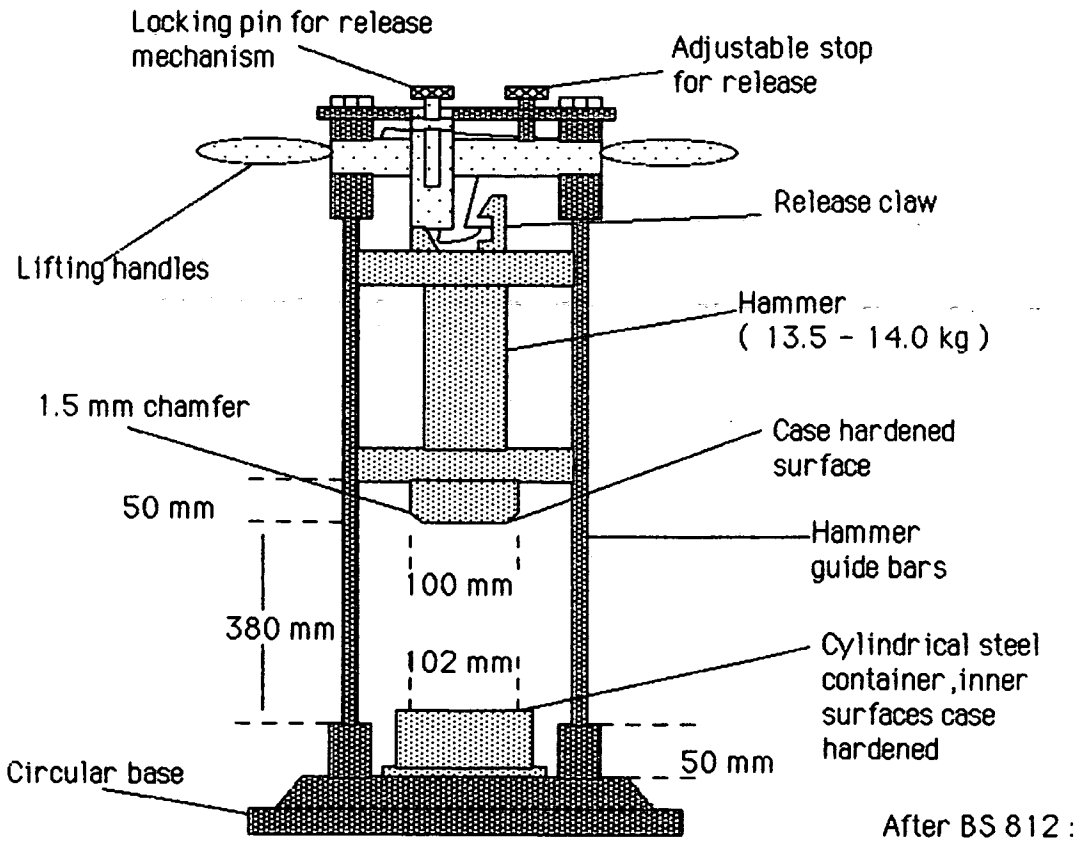


Figure 8 : Aggregate Impact tester



After BS 812 : (Part 3 : 1975)